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ACCELERATOR DEPARTMENT
Annual Progress Report
1 January - 31 December 1980

Abstract. A description is given of work in the fields of irradiation technology, chemical dosimetry, radiation chemistry, physical dosimetry and radiation bacteriology research, as well as of the operation of various irradiation facilities.

INIS-descriptors: ACCELERATOR FACILITIES, BACTERIA, DOSIMETERS, DOSIMETRY, IRRADIATION DEVICES, RADIATION CHEMISTRY, RESEARCH PROGRAMS, RISOE NATIONAL LABORATORY.

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PREFACE

The objective of the Accelerator Department is to contribute to research, development, and the implementation of processes based on ionizing radiation; thus, the following activities are carried out:

- Operation and maintenance of the irradiation facilities (three electron accelerators and three ^{60}Co-units).
- Radiation chemistry research of fundamental and applied problems in chemistry. The applied techniques include pulse- and steady-state radiolysis as well as computer simulation.
- Radiation dosimetry research with respect to proper application of dose meters as well as to basic understanding of radiation absorption processes.
- Radiation bacteriological research mainly in relation to radiation sterilization problems and radiation-resistant microorganisms, and also to increase basic knowledge of the radiation resistance mechanism. Production and supply of bacteriological standard preparations for control of irradiation sterilization plants.
- Development and construction of equipment for radiation experiments and for customer irradiation service. Upgrading of irradiation facilities.
- Customers services, including test and pilot irradiations, control and measurements, and advisory assistance.

The principal activities in these fields are described in this report which covers the period from 1 January to 31 December 1980. The contributions marked with § are abstracts of published articles.

1. OPERATION AND MAINTENANCE OF IRRADIATION FACILITIES

(J. Fenger and B. Lynggård)

1.1 HRC electron linear accelerator

The accelerator has been in operation for a normal number of hours. The weekly schedule for running the facility is four days for experimental irradiation, mostly in connection with the pulse radiolysis equipment, half a day for service irradiation, and half a day for maintenance. During shut-down periods work has been carried out as follows:

Master trigger generator: To obtain a more versatile and precise synchronization of the pulse radiolysis equipment, the capability of the accelerator master trigger generator was expanded with some trigger signals advanced from 4 ms to 10 μs compared with the electron pulse.

Microwave system: Due to repeating problems with the 2856 MHz driver generator, a test set-up was developed. By means of this equipment some of the repairs performed earlier in the USA now can be carried out in the Department.

Due to breakdown of the diodes in the previous only one-year-old high voltage rectifier (delivered by Haimson), a new rectifier was installed. The new one, designed by the Department, is based on a more conservative concept: the diodes used are of the avalanche type. During one-half year of operation there have been no problems.

For a period of time, problems with voltage flash-over occurred in the capacitor bank of the high voltage modulator. A loose connection in a strip-line representing a high resistance caused wavefronts resulting in the flash-over. The problem has been solved.

Beam-handling system

Two beam-position monitors, designed by the Department, were installed in the beam-handling system. The monitors measure the position of the beam to an accuracy of ± 0.25 mm. Besides the indication of the position, the monitors measure the magnitude of the beam current. In the future an easy-to-use instrument will be developed for routine use.

A beam tube and beam window, designed in the Department, were installed on the SM1-4 beam port. The tube is used in connection with an experimental set-up for track structure measurements.

One of the three 100 l/s vacuum, replaced due to reduced pumping efficiency in 1979, was repaired in the Department. An efficient vacuum-cleaning procedure has been developed.

1.2 Febetron, field-emission accelerator

The field-emission accelerator was used for pulse radiolysis of liquids and gases. About the end of the year some experiments indicated instabilities in pulse-to-pulse reproducibility. About 50 pulses into a Faraday cup did not verify instabilities, but a general overhaul - scheduled for summer 1980 and later postponed to summer 1981 - was initiated. There were two defective modules in the capacitor bank. The overhaul has not been completed.

1.3 ICT, low energy accelerator

A new beam catcher was installed on the low energy accelerator. The accelerator was used for crosslinking experiments. Its operation was troublefree.

1.4 10.000 Ci ^{60}Co-facility

The 10.000 Ci ^{60}Co-facility was used for radiation research and for customer services. It further serves as a reference source for microbiological efficiency testing according to the IAEA's recommendations for the radiation sterilization of medical products.

1.5 5.000 Ci ^{60}Co-facility

The 5.000 Ci ^{60}Co-cell, presently located in the Control Department of "Statens Seruminstitut", Copenhagen, was used for bacteriological research.

1.6 3.000 Ci ^{60}Co-facility

The 3.000 Ci ^{60}Co-cell was used for research in radiation chemistry, radiation bacteriology and customer services.

2. EXPERIMENTAL EQUIPMENT

2.1 Experimental equipment for irradiation of the dye film dose meter with high LET-particles

(J.W. Hansen)

An experimental equipment for track structure measurements of heavy-ions has been finished and tested. Unfortunately, the construction of the Faraday cup and the beam geometry- and charge defining slits proved inadequate and has to be changed. The constructional idea of the equipment in general seems to be in accordance with the original ideas.

2.2 Position monitors for the linear accelerator

(J.W. Hansen)

The construction of the beam position monitors has been finished. The monitors were installed and operate intentionally.

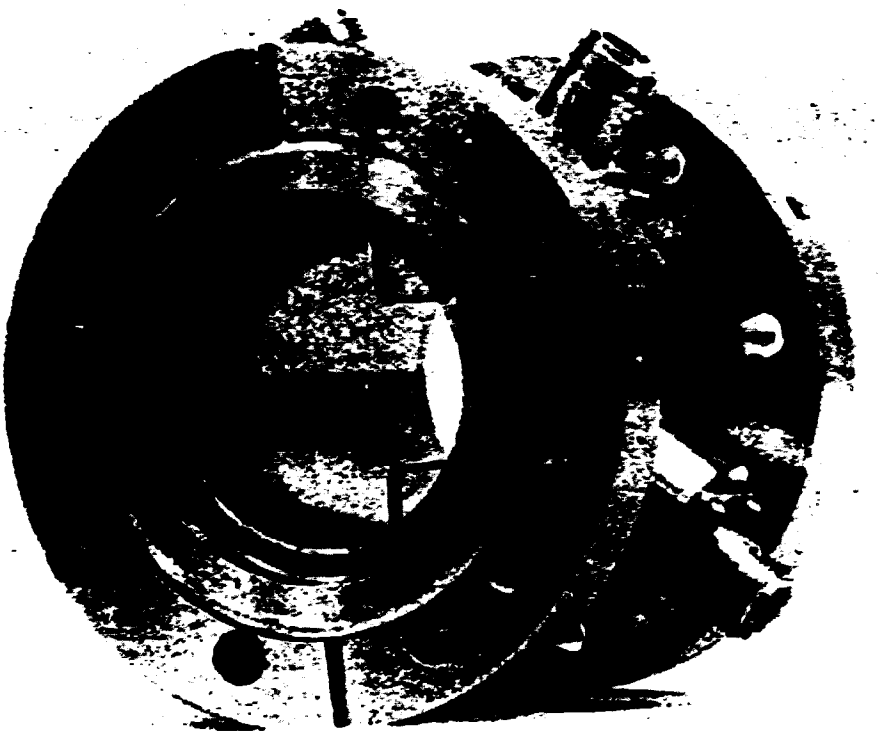

Fig. 1. A non-intercepting beam current and position monitor for the Linac.

2.3 Plotter

(B. Lynggård)

An X-Y plotter was connected to the telephone line to the Burroughs 6700 computer. Rise plotter programs store information about plots in plotter files. The information can be interpreted for plots on the central X-Y plotter, line printer, or graphic display. Procedures were written which interpret the information for plots on the local plotter.

2.4 Pulse radiolysis equipment

(B. Lynggård)

A digital storage oscilloscope was installed in the pulse radiolysis equipment with a background storage facility on flexible disks.

An interface was built between the oscilloscope and a PDP8-I computer, and programs were written so that simple calculations can be performed on the stored data: averaging, conversion to extension, 1st- and 2nd-order functions, and least-square fit of a straight line to the stored or processed data.

2.5 Thermistor calibration equipment

(B. Lynggård)

An interface was built between the digital voltmeter used for calibrating thermistors for calorimeters, the HP9810 calculator used for calorimeter dosimetry, and a PDP8-I computer. Programs were written so that the computer can read the digital voltmeter, calculate the different constants for each calorimeter, and write the information to the calculator, where they can be stored on magnetic cards and used for the dosimetry.

2.6 Nanosecond light pulser

(J. Fenger)

A nanosecond light pulser for testing the pulse radiolysis photomultiplier has been developed. The wavelength of the light pulse is 660 nm, rise and fall time < 5 ns.

2.7 Test set-up for linearity measurement of photomultiplier

(J. Fenger)

A simple test set-up and procedure for a linearity measurement of the photomultiplier has been developed. Linearity can be determined to within an accuracy of 0.1 percent.

2.8 Reference

J. Fenger, High Intensity Stabilized Pulsed Analyzing Lamp for Ultraviolet Transient Spectrometry.
Submitted to Review of Scientific Instruments.

3. CHEMICAL DOSIMETRY AND RADIATION CHEMISTRY

3.1 Radiolysis of salt brine

(E. Bjergbakke)

This work was completed according to the agreement between Risø and Elsam/Elkraft concerning advisory assistance from Risø to the Elsam/Elkraft's waste management project, phase 2.

This work was finished and a report submitted in February.

3.2 Computer simulation of the reactions in the Fricke dosimeter with varying Cl^- concentrations

(E. Bjergbakke)

This work is performed in colla oration with J. Swallow, Christie Hospital & Holt Radium Institute, Manchester, and B. Parsons, Kelsterston College, N.E. Wales Institute of Higher Education.

The possible role of a reaction of H_2O_2 with Cl_2 was determined to be insignificant by simple competition experiments. Computer simulations showed that a reaction between Cl_2 and HO_2 would give agreement between experiments and computations. This reaction was later confirmed experimentally in Manchester.

3.3 Pulse radiolysis of Cl^- solutions

(J. Holcman, E. Bjergbakke and K. Sehested)

The study has been continued combining high pressure of hydrogen gas with N_2O or $S_2O_8^{--}$ in order to scavenge e^-_{aq}. It was found that hydrogen is consumed by OH and ClOH radicals with nearly identical rate constants, while no reaction between Cl_2^- and H_2 has been observed. This presents the possibility of differentiating between Cl_2^- radicals originated by hydroxyl radicals and those formed by a direct energy absorption in Cl^- ions. A certain amount of unscavengable Cl_2^- has been found at the high pressure of H_2 and N_2O in solutions up to 4 M chloride.

3.4 Direct effect of radiation on ClO_4^-

(K. Sehested, E. Bjergbakke and E.J. Hart (Port Angeles, WA, USA))

The measurements of concentrated solutions of $NaClO_4$ exposed to pulsed irradiation have continued. The excited perchlorate ion yields mainly chlorate, oxygen, and hydrogen peroxide. An attempt to study the role of ppm impurities on the mechanism has been made by using different branches of sodium perchlorate and recrystalized perchlorate. The measured yields are not conclusive and the lack of material balance does not suggest a simple mechanism. The rather high yields of hydrogen peroxide and chlorate, however, lead to the assumption that an oxygen atom may form from the excited perchlorate ion.

3.5 Oxygen atoms in photolysis of $NaClO_4$

(E. Bjergbakke, K. Sehested and E.J. Hart (Port Angeles, WA, USA))

The work in gaschromatographic determinations of H_2 and O_2 yields in the photolysis of concentrated $NaClO_4$ solutions was continued. The photolysis was done at 257 nm and 184 nm in an attempt to determine the difference in mechanism when singlet oxygen atoms and triplet oxygen atoms react with $NaClO_4$.

3.6 Laser flash photolysis and pulse radiolysis of iodate and periodate in aqueous solution properties of iodine (VI)[§]

(U.K. Kläning (Kemisk Institut, Aarhus Universitet), K. Sehested, and Th. Wolff (Universität Gesamthochschule, Siegen, Germany))

Species containing iodine in the oxidation state six are formed by photolysis and radiolysis of aqueous iodate and periodate solutions in the following reactions: $IO_3^- + O^- \rightarrow IO_4^{2-}$; $IO_3^- + OH \rightarrow IO_3$; $I^{VII} + e_{aq}^- \rightarrow I_e^{VI}$, and $I^{VII} \xrightarrow{h\nu} I_o^{VI} + O^-$ (or OH). The present pulse radiolysis- and laser flash photolysis study of I_e^{VI} and I_o^{VI} suggests that the predominant I_e^{VI} and I_o^{VI} species formed are IO_4^{2-} and IO_3 at $3 < pH < 7$, $H_5IO_6^-$ and $H_2IO_5^{2-}$ at $8 < pH < 11$ and $H_4IO_6^{2-}$ and HIO_5^{3-} at $pH > 12$. Redox reactions of the iodine (VI) species are fast compared to interconversion among the various iodine (VI) species. The assumed four-, five-, and six-coordinated iodine (VI) species have similar spectra and decay kinetics, and negative values of the standard Gibbs energy of formation. The spectrum and decay kinetics of the assumed IO_3 are markedly different. Furthermore, the standard Gibbs energy of formation of IO_3 is estimated to have a large positive value. Observations of reactivity of iodine (VI) towards tert-butanol and periodate suggest that reduction of iodine (VI) to iodate takes place by transfer of OH as a rule.

3.7 Pulse radiolysis of BrO_3^-

(N. Bjerre and U.K. Kläning (Kemisk Institut, Aarhus Universitet) and K. Sehested)

The reaction of O^- with BrO_3^- was studied by pulse radiolysis of aqueous solutions of BrO_3^- saturated with N_2O at various pressures and by measurements of radiation-induced oxygen isotope exchange. Preliminary results indicate a fast reversible reaction $BrO_3^- + O^- \rightleftarrows BrO_4^{2-}$. The reverse reaction has previously been studied in perbromate solutions, where the solvated electron reacts with perbromate yielding O^- (K.J. Olsen, K. Sehested and E.H. Appelman, 1973).

3.8 Radiation chemistry of xenon trioxide, xenate and perxenate, and photochemistry of perxenate. A pulse radiolysis and laser photolysis study[§]

(U.K. Kläning (Kemisk Institut, Aarhus Universitet), K. Sehested, Th. Wolff (Universität Gesamthochschule, Siegen, Germany), and E.H. Appelman (Argonne National Laboratory, Argonne, Ill., USA))

The radiation chemistry of xenon trioxide, XeO_3, xenate, $HXeO_4^-$, and perxenate $HXeO_6^{3-}$ in aqueous solution was studied by pulse radiolysis, and the photochemistry of perxenate in aqueous solution by laser flash photolysis. Radiation-produced unstable species containing xenon in the formal oxidation state five, (XeO_3^-), seven ($HXeO_4$, $HXeO_5^{2-}$, $H_3XeO_6^{2-}$), and nine ($H_3XeO_7^{2-}$) have properties very similar to iodine species in the formal oxidation states four, six, and eight. The xenon species are formed in the following reactions:

1) with e_{aq}^-: $XeO_3 + e_{aq}^- \rightarrow XeO_3^-$, $HXeO_6^{3-} + e_{aq}^- \xrightarrow{H_2O} H_3XeO_6^{2-}$;

2) with OH : $XeO_3 + OH \rightarrow HXeO_4$, $HXeO_6^{3-} + OH \xrightarrow{H_2O} H_3XeO_7^{2-}$ (in which reactions OH adds to a ligand oxygen atom with formation of peroxycompounds);

3) with O^- : $HXeO_4^- + O^- \rightarrow HXeO_5^{2-}$ (in which reactions O^- adds to the xenon atom);

4) by photolysis $HXeO_6^{3-} \xrightarrow{h\nu} HXeO_5^{2-} + O^-$.

The species $HXeO_5^{2-}$ and $H_3XeO_6^{2-}$ dissociate to xenate and O^- or react with perxenate with formation of an intervalence complex which subsequently decomposes to xenate and $H_3XeO_7^{2-}$. $H_3XeO_7^{2-}$ and its complex with perxenate both form xenate perxenate and oxygen. Estimated values of standard Gibbs energy of formation of the xenon species are used for selecting thermodynamically feasible mechanisms for one-electron reduction of perxenate and for the decomposition of perxenate in acid solution.

3.9 Aqueous solutions of ozone

(K. Sehested, J. Holcman and E.J. Hart (Port Angeles, WA, USA))

A pulse radiolysis study of aqueous ozone solutions has been undertaken to determine the rate constants of the free radical reactions involved in its chain decomposition initiated by ionizing radiation. The ozonide ion was found as a product from the reaction with the hydrated electron and it was identified by its optical absorption at 430 nm. Also, peroxyradicals seem to form ozonide ions in a slower process. The ozonide ions have been observed in the pH range from 7.5 to 11. The decay of the ozonide ions takes place more rapidly at lower pH's and there are indications that it also reacts with the borax-buffer in buffered solutions. The mechanism is not fully understood and seems to be rather complicated as the yields of ozonide ion are strongly concentration dependent and always much lower than the total radical yields.

3.10 The ozonide radical ion

(K. Sehested, J. Holcman, E. Bjergbakke and E.J. Hart (Port Angeles, WA, USA))

The decay of the ozonide radical ion in oxygenated alkaline solution is not well understood. A study with high pressure of N_2O and mixtures of N_2O and O_2 has been started to obtain improved knowledge of the behaviour of the O_3^-. It is found that the ozonide ion has no absorption in near UV where O_2^- absorbs. The experiments are done at various pH's higher than 10 and a computer program for simulating the formation and decay has been worked out. The preliminary data are rather well fitted by the applied new mechanism.

3.11 Pulse radiolysis at high temperatures and high pressures. II.[5]

(H. Christensen (Studsvik Energiteknik AB, Studsvik, Sweden) and K. Sehested)

A set-up enabling pulse radiolysis measurements at high tempera-

tures (up to 320°C) and high pressures (up to 140 bar) has been constructed in collaboration between Risø National Laboratory and Studsvik Energiteknik. The cell has been used for experiments with aqueous solutions with the purpose of determining activation energies for reactions of importance in reactor chemistry. The activation energy of the reaction $e^-_{aq} + e^-_{aq}$ has been determined to be 22 kJ·mol^{-1} (5.3 kcal·mol^{-1}) in good agreement with literature values. Furthermore, the activation energies of the reactions Cu^{2+} + OH (13.3 kJ·mol^{-1}, 3.2 kcal·mol^{-1}), and OH + OH (tentatively 8 kJ·mol^{-1}, 1.9 kcal·mol^{-1}) have been found. The absorption spectrum of the OH radical has been measured up to temperatures of 200°C. The absorption maximum is found at 230 nm at all temperatures.

The reaction between Fe^{2+} and OH radicals has been studied up to a temperature of 220°C. An activation energy of 9 kJ·mol^{-1} (2.2 kcal·mol^{-1}) has been determined and the spectrum of the transient formed in the reaction has been found at different temperatures.

3.12 Reaction of OH radicals with H_2O_2

(H. Christensen (Studsvik Energiteknik AB, Studsvik, Sweden) and K. Sehested)

The reaction of hydroxyl radicals with hydrogen peroxide has been studied at various pH's in the temperature range 14-160°C. The activation energy of the overall reaction at pH ∿ 8 was found to be 14 kJ·mol^{-1} (3.4 kcal·mol^{-1}). The rate constant as measured by the increase of O_2^- absorption at 265 nm increases with pH. Below pH 8.5 the rate constant is $2.7 \cdot 10^7$ M^{-1}s^{-1}. The increase with pH is caused by rising contribution from the reaction

$$OH + HO_2^- \rightarrow O_2^- + H_2O \qquad (1)$$

From a plot of the overall rate constant against pH, $k_{(1)}$ was preliminary determined to be of the order of 10^{10} M^{-1}s^{-1}. Another reaction that may influence the overall rate is

$$O^- + H_2O_2 \rightarrow O_2^- + H_2O \qquad (2)$$

$k_{(2)}$ was found to be less than 10^9 M^{-1}s^{-1}.

3.13 The peroxyradical at elevated temperature

(H. Christensen (Studsvik Energiteknik AB, Studsvik, Sweden) and K. Sehested)

The spectrum of the peroxyradical was measured at various temperatures in the pH range 8 to 11 with 70 atm H_2 pressure. The spectrum changes only slightly with increasing temperature with a redshift of 5 to 10 nm at 200°C. The $G\varepsilon$, however, increases almost twofold from 20°C to 125-150°C, but stays fairly constant from 150 to 250°C. The decay kinetics are second order up to 150°C with a common activation energy, but above that temperature it becomes mixed kinetics with a sudden increase in the disappearance rate by two orders of magnitude.

3.14 A pulse radiolysis study of aqueous methylviologen (1.1'-dimethyl-4.4'-bipyridylium)

(N. Getoff and S. Solar (Institut für Strahlenchemie, Vienna, Austria), J. Holcman and K. Sehested)

Methylviologen is widely used as mediator in photochemical systems for solar energy conversion, and a pulse radiolysis study will be relevant for solving the problems of stability of methylviologen in these systems.

Aqueous solutions of methylviologen (MV^{2+}) have been studied. The rate constant for the reaction of e^-_{aq} with MV^{2+} was found to be $k_{e^-_{aq}} = 7.3 \times 10^{10}$ $M^{-1}s^{-1}$ and the absorption of the product of this reaction was $\lambda_{max} = 392.5$ nm with $\varepsilon = 40.900$ $M^{-1}cm^{-1}$ in good agreement with literature values.

The H radicals react with MV^{2+}, with $k_H = 1.4 \times 10^9$ forming a product which absorbs at $\lambda = 392.5$ nm, $\varepsilon = 14.200$ $M^{-1}cm^{-1}$ and $\lambda = 600$ nm, $\varepsilon = 8.700$ $M^{-1}cm^{-1}$. The product decays in a second-order process with $2k = 7.9 \times 10^6$ $M^{-1}s^{-1}$.

The OH radical reaction with MV^{2+} has been studied under various experimental conditions. The rate constant for the reaction varies from 1 to 6×10^8 $M^{-1}s^{-1}$ and the products absorb at 392,

470, and 600 nm. The results indicate a complex mechanism and more experiments are needed to clarify it.

3.15 Pulse radiolysis of alkylated anilines

(I. Karaivanov (Institute of Nuclear Research and Nuclear Energy, Sofia, Bulgaria) and J. Holcman)

A pulse radiolitic study of radical cations of dimethylaniline has been continued. It has been found that radical cations of N,N-dimethylaniline and N,N-diethylaniline in 0.6 M NaOH solution lose a proton from a methyl and an ethyl group, respectively. The expected formation of the respective OH-adducts has not been observed. Their formation, however, followed by a rapid water elimination reaction cannot be excluded.

3.16 Solar energy at Risø

(J. Holcman)

An account has been given on the photochemical solar energy conversion to fuel or electrical power with its focus on future research activities in this area. The contribution is part of a final report from the solar energy working group at Risø (Solenergi på Risø).

3.17 References

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4. PHYSICAL DOSIMETRY AND TECHNOLOGICAL APPLICATION OF RADIATION

4.1 Radiochromic dye film dose meters

(A. Miller, J.W. Hansen, W. Batsberg Pedersen (Chemistry Dept.), and W.L. McLaughlin (National Bureau of Standards, Washington, D.C., USA))

Thin-film plastic dose meters are being produced and investigated. A portion of this work is performed under a research contract with IAEA (2051/RB). The contract is part of IAEA's coordinated research program in the field of high dose dosimetry for industrial processing. The work, which was summarized in a status report (Risø-M-2254), has included testing of a dose meter's dependence on dose rate and relative humidity. We observed a decrease of ~ 15% at lower γ-ray dose rates, and the response of the dose meter may increase ~ 5% for each 10% increase in relative humidity.

The possibility of utilizing the dose meter's UV-light sensitivity has been investigated further. It may be possible to increase the sensitivity by incorporating UV-emitting scintillators in the plastic matrix.

4.2 International dose intercomparison

(A. Miller)

IAEA is organizing a program with the aim of establishing an international dose measurement service for industrial plants. At an advisory group meeting in Vienna the status of the program

was reviewed, but unexpected problems have delayed the start of the service for cobalt plants (dose range 0.5-10 Mrad). At the meeting a paper was given on the results under IAEA research contract 2051/RB.

4.3 Dose measurements

(A. Miller, W. Batsberg Pedersen (Chemistry Dept.), and W.L. McLaughlin (National Bureau of Standards, Washington, D.C.,USA))

The dose meter films have been used for measuring dose and dose distributions in connection with various experiments and for customers. Some of these measurements were presented at the 3rd. International Meeting on Radiation Processing, Tokyo.

A program for our desk top calculator HP 9830A has been developed, which can calculate energy dependence of dose meters, based on Burlin's general cavity theory.

4.4 Induced radioactivity

(A. Miller and P. Hedemann Jensen (Safety Dept.))

Because of time limitation only a few preliminary measurements have been carried out. A contract proposal was turned down by the IAEA due to lack of funds.

4.5 Commercial activities

(A. Miller and W. Batsberg Pedersen (Chemistry Dept.))

In cooperation with the Chemistry Department an effort is made to promote ionizing radiation as an industrial process:

- Test irradiations have been carried out for several firms,
- Participation in meetings on radiation processing in:
  - Hamburg (organized by Radiation Dynamics Inc.),
  - Copenhagen (organized by Association International d'Irradiation Industrielle),

- Tokyo (3rd. International Meeting on Radiation Processing),
- In cooperation with the Danish Society for Polymer Technology we organized a meeting on Radiation Processing at Risø.

4.6 Microdosimetry

(J.W. Hansen, Kjeld Olsen (Dept. of Radiophysics, Københavns Amts Sygehus, Herlev), and R. Katz (University of Nebraska-Lincoln, Lincoln, USA))

A detailed investigation of the track structure theory for high-LET radiation developed by R. Katz has been attempted, and the predictions of the theory have been tested experimentally by using a thin-film radiochromic dye cyanide plastic dose meter.

The theory stresses the similarity between high- and low-LET radiation by pointing to the conclusion that the main effects of high-LET radiation are due to low-energy delta rays ejected from the particle track. The main difference between high- and low-LET radiation is thus due to the highly inhomogeneous dose distribution from high-LET radiation.

The track structure theory provides a formula for calculating the dose distribution around the particle track. From this distribution the interaction cross-section of high-LET radiation can be calculated using detector parameters derived from experiments with low-LET radiation combined with the ion beam parameters.

The theory has been tested experimentally by means of a radiochromic dye cyanide film detector which has been thoroughly investigated in our Department. By measuring the change in optical density as a function of the dose, the effectiveness of high-LET radiation relative to low-LET radiation is determined.

^{60}Co-gamma radiation is used as a standard for low-LET radiation and for measuring D37, which for this dose meter is 17 Mrad.

The dose of D37 is characteristic for the detector for which 63% of the detector sensitive elements are activated.

High-LET radiation ranging from 16-MeV protons to 3 MeV/amu ^{14}N ions with a LET range of 32-7000 $MeVcm^2g^{-1}$ was obtained from the tandem accelerator at Niels Bohr Institute.

In the calculations of the theoretical effectiveness the extended target formalism has been used, i.e. the detector is assumed to be made up of sensitive elements considered as cylinders with the cylinder axis parallel to the particle track. The dose is averaged over the volume of the sensitive element, and the activation probability is calculated from the Poisson statistics assuming the detector to behave like a one-hit detector. A computer program for our HP 9830 desk top calculator has been written to determine the dose distribution into large distances around the track of the charged particle.

Theexperimental and theoretical effectiveness agree within the experimental uncertainty of 5%, which is remarkable considering the range in LET.

At very high doses, for example, 100-500 Mrad, the film no longer behaves like a single hit detector since a bleaching effect is observed, which is not yet fully understood. This effect has little influence on the determination of the effectiveness, which is made at doses below 10 Mrad.

4.7 Detection of individual tracks of heavy ions in the thin-film detector

(J.W. Hansen and R. Katz (University of Nebraska-Lincoln, Lincoln, USA))

A work has been initiated on another test of the theory in which our thin-film detector is being irradiated with 10 MeV/amu ^{238}U-ions from the heavy ion linac accelerator at Gesellschaft für Schwerionen Forschung in Darmstadt(Gerhard Kraft).

From calculations on the dose-effect profile around the track of a densely ionizing heavy particle in the detector it should be possible to determine tracks of individual particles visually in a microscope. The track profile for 10 MeV/amu ^{238}U-ions shows a radius of 1.7×10^{-5} cm at a dose level of 0.1 Mrad. Calculations indicate that the 10 MeV/amu is an optimum energy regarding track width and range for our detector.

4.8 References

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5. RADIATION BACTERIOLOGY RESEARCH

Bacteriological research concerns the development and testing of radiation sterilization processes, as well as giving advice and assistance on specific projects to prospective users of radiation sterilization. Research interests are concentrated on the mechanisms of radiation resistance.

5.1 Mutants of M. radiodurans with altered response to DNA damage

(M. Trier Hansen)

A number of mutant strains of M. radiodurans were examined for defects or alterations in radiation-inducible DNA-repair systems. In the first phase, a selection scheme was designed to obtain mutants constitutive for the synthesis of repair enzymes. In the wild type cells, inhibition of protein synthesis by chloramphenicol after exposure to radiation prevents the production of repair enzymes and causes a pronounced sensitization. After an otherwise sublethal dose the survival falls to about 0.1% as a consequence of blockage of protein synthesis. This phenomenon was utilized in the selection procedure which consisted of cyclings of exposure to sublethal radiation followed by chloramphenicol treatment. Two types of mutants were selected; some which were superresistant to radiation and others in which inhibition of protein synthesis by chloramphenicol was leaky. Both types had considerably decreased growth rates. Despite the sizeable selective advantage which a constitutive repair system would convey to the cell, no mutants of this class were obtained. This could suggest that such mutants were not viable. Indeed this might be expected, if, as in E. coli, induction of repair is an integral part of a pleiotrophic cellular response which also comprises inhibition of cell division.

Secondly, mutant strains which are sensitive to DNA damage and have been genetically characterized by Dr. Moseley (University of Edinburgh) were examined for loss of one or more of the four inducible proteins which we have earlier detected in M. radio-

durans. None of the five mutants examined appears to be mutated in the structural genes for the damage inducible enzymes. One mutant strain, however, seems altered in the regulatory processes which govern induction. Most interestingly, the strain showed a changed specificity for the type of DNA damage which is able to induce the repair functions.

5.2 Sensitivity of E. coli to DNA interstrand crosslinks[§]

(M. Trier Hansen)

Experimental survival curves for Escherichia coli K 12 (CR 34) were determined after exposure to 4,5',8-trimethylpsoralen and near ultraviolet light. The lethal action was shown to arise exclusively from interstrand crosslinks; cell vulnerability increased markedly with the doubling time of the culture.

In order to account for these results, two quite different models are considered. The first assumes that a cell survives as long as at least one copy of its genome remains undamaged; a variant of this permits repair by DNA strand exchanges. The second model allows for a limited period of time during which DNA repair can take place. A crosslink in a stretch of DNA due to be replicated within this interval constitutes a fatal lesion.

Theoretical survival curves are computed for bacterial populations with defined age distributions and chromosome configurations. While the first model completely fails to provide a satisfactory description of the experimental results, the second model does predict the presence of a shoulder in the survival curves and, in one of its forms, it seems to agree rather well with the measured data over a wide range of crosslink concentrations and doubling times.

5.3 W-reactivation in Acinetobacter calcoaceticus

(D. Berenstein)

W-reactivation in Acinetobacter calcoaceticus may indicate de novo synthesis of proteins inducible by irradiation and involved

in repair of DNA damage. Incubation of wild-type cells after irradiation and before plating with the irradiated phage showed some increase in phage survival. But a termination of protein synthesis in an auxotrophic mutant by deprival of the required amoniacid gave the same increase in phage survival. Antibiotics known to stop protein synthesis could not be used, as they cause death of Acinetobacter cells. An Acinetobacter mutant that stops to synthesize proteins and survives chloramphenicol treatment has been isolated. There is no pronounced difference in the capacity to reactivate the irradiated phage when the irradiated mutant cells are incubated in broth with or without chloramphenicol. Inhibition of protein synthesis by chloramphenicol after irradiation results in only minor sensitization of Acinetobacter cells, in contrast to both E. coli and Micrococcus radiodurans. Thus, W-reactivation in Acinetobacter does not seem to require substantial de novo protein synthesis. Still, there is about 4% of protein synthesis going on in the presence of chloramphenicol, so it is possible that there exists a de novo protein synthesis step that is chloramphenicol resistant.

W-reactivation in E. coli is a mutagenic process. Acinetobacter does not show an increase in mutation frequency measured as ratio clear/turbid plaque formers under the conditions of W-reactivation. The lack of mutation accompanying W-reactivation has also been reported for Haemophilus influenzae.

5.4 Customer service for hospitals, research laboratories, and industry

(D. Berenstein and M. Trier Hansen)

The following services were maintained:

- General consultation, irradiation of test specimens, evaluation of materials, and packagings in relation to the introduction of new hospital equipment.
- Irradiation of pharmaceutical materials and fodders in order to reduce the initial number of bacteria.

5.5 References

N.B. Grover, A. Margalit, Z. Zaritsky, E. Ben-Hur and M.T. Hansen, Sensitivity of exponentially growing populations of Escherichia coli to photo-induced psoralen-DNA interstrand crosslinks. Biophys. J. 33 (1981) 93-106.

6. EDUCATIONAL ACTIVITIES AND PUBLICATIONS

6.1 Lectures

D. Berenstein, Strålesterilisation af Medicinsk Éngangsudstyr (Radiation Sterilization of Medical Equipment) for studerende ved Danmarks Sygeplejeskole. Risø, 6. November.

H. Christensen and K. Sehested, Pulse Radiolysis at High Temperatures and High Pressures. II. 3. International Meeting on Radiation Processing, Tokyo, Japan, 25. October - 7. November.

N. Getoff, Possibilities of Photochemical and Photoelectrochemical Utilization of Solar Energy. Risø, 15. July.

J.W. Hansen, Den Alternative Energiforskning på Risø (Alternative Energy Research at Risø). Bernadotteskolen, Hellerup, 19. March.

J.W. Hansen, M. Jensen and R. Katz, The Radiochromic Dye Film Dose Meter as a Test of Particle Track Theory. 7. Symposium on Microdosimetry, Oxford, U.K., 8-12. September.

M. Jensen, Track Theory of Katz and Nuclear Emulsion. Risø, 16. April.

U.K. Kläning, K. Sehested and Th. Wolff, Iodine (VI) in Aqueous Solution. A Laser Flash Photolysis and Pulse Radiolysis Study. Symposium on Fast Reactions, Göttingen, Germany, 2-4. September.

U.K. Kläning, K. Sehested and Th. Wolff, Radiation Chemistry and Photochemistry of Inorganic Oxyanions of Non-Transition Elements. Max Planck Institut für Biophysikalische Chemie, Göttingen, Germany, 12. November.

W.L. McLaughlin, J.C. Humphreys and A. Miller, Traceability for Ionizing Radiation Measurements. Proceedings of NBS Seminar, 8-9. May. National Bureau of Standards, Washington, D.C., USA.

W.L. McLaughlin, J.C. Humphreys, H. Levine, A. Miller , B.B. Radak and N. Rativanich, The Gamma-Ray Response of Radiochromic Dye Films at Different Absorbed Dose Rates. 3. International Meeting on Radiation Processing, Tokyo, Japan, 25. October - 7. November.

A. Miller and W. Batsberg Pedersen, Dose Distribution in Electron Irradiated Plastic Tubing. 3. International Meeting on Radiation Processing, Tokyo, Japan, 25. October - 7. November.

A. Miller, Current Investigations of Radiochromic Dye Dosimeters. Advisory Group Meeting on Dosimetry for High Doses Employed in Industrial Radiation Processing. IAEA, Vienna, Austria, 17-21. November.

A. Miller, Stråling og Strålingskilder (Radiation and Radiation Sources). Polymerteknisk Selskab's (DiF) møde om "Modificering af plast ved ioniserende bestråling". Risø, 27. November.

N. Rativanich, B.B. Radak, A. Miller, R.M. Uribe and W.L. McLaughlin, Liquid Radiochromic Dosimetry. 3. International Meeting on Radiation Processing, Tokyo, Japan, 25. October - 7. November.

6.2 Publications

Accelerator Department Annual Progress Report (1980), 1 January - 31 December 1979. Risø-M-2231.

E. Bjergbakke (1980), Radiolysis of Salt-Brine. This report has been worked out according to the agreement between Risø National Laboratory and Elsam/Elkraft concerning advisory assistance from Risø to Elsam/Elkraft's waste management project, phase 2. February.

H. Christensen and K. Sehested (1980), Pulse Radiolysis at High Temperatures and High Pressures. Radiat. Phys. Chem. 16, 183-186.

J.W. Hansen (1980), Conceptual Basis for the Radiochromic Dye Film Dose Meter as a Test of Particle Track Theory. Risø-M-2232.

J.W. Hansen, M. Jensen and R. Katz (1980), The Radiochromic Dye Film Dose Meter as a Test of Particle Track Theory. Risø-M-2243.

M. Trier Hansen (1980), Four Proteins Synthesized in Response to DNA Damage in Micrococcus radiodurans. J. Bacteriol. 141, 81-86.

J. Holcman (1980), Photokemisk Udnyttelse af Solenergi. Arbejdsgruppen for "Solenergi på Risø".

A.G. Karadjov and J.W. Hansen (1980), Estimation of Electron Dose Delivered by a 0.4 MeV Accelerator from Bremsstrahlung Dose Measurements. Radiat. Phys. Chem. 15, 623-626.

W.L. McLaughlin, A. Miller, S.C. Ellis, A.C. Lucas and B.M.Kapsar, (1980), Radiation-Induced Color Centers in LiF for Dosimetry at High Absorbed Dose Rates. Nucl. Instrum. & Meth. 175, 17-18.

A. Miller and W.L. McLaughlin (1980), On the Radiochromic Dye Dose Meter. Progress Report (1. Nov. 1979 - 31 Oct. 1980). IAEA Research Contract No. 2051/R3/RB.

A. Miller and W.L. McLaughlin (1980), On a Radiochromic Dye Dose Meter. Risø-M-2254.

6.3 Test-irradiations

Test-irradiations were carried out for:

Fa. Alfred Benzon, København
Daoplast A/S, Asnæs
Danmarks tekniske Højskole, Lyngby
Den kgl. Veterinær- og Landbohøjskole, København
Fibiger-Laboratoriet, København
Fa. Litex, Vallensbæk
A/S Meda, Vanløse
Dyrlæge Møller Nielsen, Ry
A/S Nunc, Kamstrup
Marselisborg Hospital, Aarhus
Mölnlycke A/S, Espergærde

Proteinlaboratoriet, Københavns Universitet
Raychem ApS, Glostrup
Aarhus Kommunehospital, Aarhus
Aarhus Universitet, Aarhus.

6.4 Visiting scientists

J. Bergström, Studsvik Energiteknik AB, Studsvik, Sweden.
N. Bjerre, Kemisk Institut, Aarhus Universitet, Aarhus.
A. Charlesby, Silver Spring, Watchfield, England.
H. Christensen, Studsvik Energiteknik AB, Studsvik, Sweden.
N. Getoff, Institut für Strahlenchemie, Vienna, Austria.
E.J. Hart, Port Angeles, WA., U.S.A.
M. Jensen, Statens Strålskydds Institut, Stockholm, Sweden.
I. Karaivanov, Institute of Nuclear Research and Nuclear Energy, Sofia, Bulgaria.
U. Kläning, Kemisk Institut, Aarhus Universitet, Aarhus.
H. Kristensen, Kontrolafdelingen, Statens Seruminstitut, København.
C.K. Larsen, Kontrolafdelingen, Statens Seruminstitut, København.
W.L. McLaughlin, National Bureau of Standards, Washington, D.C. U.S.A.
J. Morris, Chichester House, London, England.
U. Navanugraha, Biological Sciences Division, Office of Atomic Energy for Peace, Bangkok, Thailand.
J. Silverman, Institute for Physical Science and Technology, University of Maryland, Md., U.S.A.
S. Solar, Institut für Strahlenchemie, Vienna, Austria.
M. Stamenković, Belgrade, Yugoslavia.(IAESTE).
N.J. Swiderska, Kontrolafdelingen, Statens Seruminstitut, København.
H.M. Saad, Çairo, Egypt. (IAEA Stip.).

7. IRRADIATION FACILITIES AT THE ACCELERATOR DEPARTMENT

Electron Accelerators

1. Linear Electron Accelerator, Haimson Research Corp. Model HRC-712

Specifications:

Electron energy ..... 10 MeV
Average electron current ..... 1 mA
Peak electron current at 10 MeV ..... 1100 mA
Pulse length, normal mode ..... 1 - 4 μs
Pulse length, short pulse mode ..... 10 - 1000 ns
Pulse repetition rates ..... single pulses and 12.5, 25, 37.5, 50, 100, 150 and 200 pps
Energy spread ..... 78% of the beam current within a spread of ± 2.5%

Pulse-to-pulse dose variation:

a) within a pulse train, less than 1.8%

b) for single pulses separated at 10 min. intervals, less than ... 3%

Electron pulse flatness over a 2 μs interval, better than ..... ± 1%

Accelerator room beam facilities:

1. A bent beam with scan width of 40 cm providing a process irradiation capacity of 1000 - 1500 Mrad kg/hour.
2. A horizontal beam, full average beam peak power, for electron and X-ray irradiation.
3. A horizontal beam, reduced average beam power (12.5 pps) in connection with a ± 0.5% beam slit.

Target room beam facilities:

1. Three horizontal beam ports, reduced average beam power (12.5 pps).

2. Field Emission Electron Accelerator, Febetron Model 705B

Specifications:

Electron energy ..... 1.5 - 2.0 MeV
Peak electron current ..... 4000 A
Pulse length (electron mode) ..... 20 ns

3. Low-Energy Electron Accelerator, High Voltage Eng. Corp. Model EPS 400-IND

Specifications:

Electron energy ..... 400 keV
Electron current ..... 50 mA
Scan width ..... 120 cm

The accelerator is provided with conveyors to permit pilot-plant irradiation.

^{60}Co-Facilities

10,000 Ci ^{60}Co-facility (built at Risø 1957)

Designed for very homogeneous irradiation of samples with a maximum length of 1,000 mm and diameters of maximum 180, 100, or 60 mm. The corresponding maximum dose rates (9,400 Ci, 1 January 1981) are 5.7×10^5 rads/h, 1.6×10^6 rads/h, and 3.7×10^6 rads/h, respectively.

5,000 Ci ^{60}Co-facility (built at Risø 1971)

Designed for laboratory use and fitted with a 123 mm$^{\phi}$ x 150 mm irradiation chamber. The dose rate in the center of the chamber (5,700 Ci, 1 January 1981) is 4.9×10^5 rads/h. The cell is located at the Control Department, Statens Seruminstitut, Copenhagen.

3,000 Ci ^{60}Co-cell (built at Risø 1968)

Designed for laboratory use and fitted with a 120 mm$^{\phi}$ x 200 mm irradiation chamber. The dose rate in the center of the chamber (3,600 Ci, 1 January 1981) is 3.6×10^5 rads/h.

8. STAFF OF THE ACCELERATOR DEPARTMENT

Head : Knud Sehested
Office Staff: Ebba Haugaard and Ruth Madsen

Scientific staff

Dvora Berenstein
Erling Bjergbakke
Jørgen Fenger
Johnny W. Hansen
Mogens Trier Hansen
Jerzy Holcman
Ivan Karaivanov (until 31. March), Guest
Bent Lynggård
Arne Miller

Technical staff

Svend Bøjlund Andersen
Margit Elm Andersen
Karen Boysen
Erling Cederstrøm (until 30. June)
Hanne Corfitzen
Edvard Grys (until 29. February)
Ina Hansen
Inge Høegh
Dorte Færregård Jensen (1. January-30. April), Apprentice
Torben Johansen
Erik Engholm Larsen
Fritz Larsen
Inge Merete Larsen
Kirsten Bjerring Larsen (from 1. November), Apprentice
Laurits Nielsen
Gert Hagen Olsen (from 1. September)
Kresten Pejtersen
Ulla Sørensen (1. July-30. September), Apprentice
Michael Brandt Svendsen (from 1. December)
Mads Wille

Consultants

Dr. E.A. Christensen, Chief Physician, Control Department, Statens Seruminstitut, Copenhagen.

Dr. E.J. Hart, Port Angeles, WA., U.S.A.

W.L. McLaughlin, Physicist, Center for Radiation Research, National Bureau of Standards, Washington, D.C., U.S.A.

Risø National Laboratory **Risø-M-2287**

Risø-M-2287

Title and author(s)

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Date July 1981

Department or group

Accelerator Dept.

Group's own registration number(s)

36 pages + tables + illustrations

Abstract

A description is given of work in the fields of irradiation technology, chemical dosimetry, radiation chemistry, physical dosimetry and radiation bacteriology research, as well as of the operation of various irradiation facilities.

Copies to

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